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The United States Navy is focusing its best minds and research laboratories on a handful of VR projects to examine the feasibility of maintaining or improving training technologies and tactical operations. Key training objectives are to compensate for the educational levels of recruits, reduced number of skilled instructors, and reduced locations of high-quality classroom facilities. Additionally, training should be more efficient and affordable, accommodate varying geographic demands, and increase ability for team training. The objectives for tactical operations are to increase operator performance by reducing workload and consequently improving decision making.

As with any new and emerging technology, VR domain experts are being shaped overnight. The development and implementation of VR applications require a team of experts with widely different backgrounds. The Navy has assembled diverse teams with elements of science, art, design, education, security, ingenuity, and possibly a bit of magic.

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Navy special operations missions require high collective and individual performance. Virtual reality projects could help

by Mark Gembicki and David Rousseau

Naval Applications of Virtual Reality

The United States Navy is focusing its best minds and research laboratories on a handful of VR projects to examine the feasibility of maintaining or improving training technologies and tactical operations. Key training objectives are to compensate for the educational levels of recruits, reduced number of skilled instructors, and reduced locations of high-quality classroom facilities. Additionally, training should be more efficient and affordable, accommodate varying geographic demands, and increase ability for team training. The objectives for tactical operations are to increase operator performance by reducing workload and consequently improving decision making.

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Navy special operation missions are performed by SEALS (SE-Air-Land units) under the direction of the Naval Special Warfare Command. These missions demand extensive planning and seamless execution. For the training of these forces to be effective, attention must be paid to the performance of the individual as well as the collective response of the unit. A characteristic of special operations is the inability to provide real-world environments with the same fast-breaking action. However, VR systems supplied with body function information could bring these forces closer to a believable and natural simulation.

The Artisan Group is developing several VR conceptual platforms for the special operations community that could to be introduced soon. The VR simulations consist of the planning, rehearsal, and execution phases of a mission. Some simulations include Navy SEAL Mk-VIII swimmer delivery vehicles and the future Mk-V fast surface vehicle. Direct action missions with high altitude low opening, or high altitude high opening parachute insertion, demolition raids and close quarter battle environments contain multiple variables that can be adjusted in real-time.

Body function information such as blood pressure, pulse rate, fatigue, temperature, and so on, could be captured and automatically displayed in the virtual environment. A supporting brain wave measurement technology aids in the collection of critical mental performance data. The coupling of this information could produce more precise fatigue and alertness indicators, as compared to present behavioral and body function responses taken by overt methods.

Several Naval scenarios require the replacement of humans by machines for hazardous duties. The VR system makes teleoperated and robotic vehicles simpler to control, thereby reducing operator stress. By providing full immersion audio and video and realistic manual control movements at the control site, repair and maintenance of ground, air, and underwater vehicles becomes much more natural. Full immersion can be achieved from microphones and cameras positioned on the remote vehicle or site. Realistic manual control can be achieved by duplicating the physical vehicle being remotely controlled or by interpreting hand, foot, head, and eye [illegible] tactile or optical sensors.

Team training and individual training exercises can be expensive. A VR system provides a simulated wargaming environment for multi-unit tactics coordination. By providing full immersion helmet-mounted units, the need for the physical simulators is eliminated. By tracking hand and body movement, the physical actions required in today's simulators can be replicated without the need for the physical mockup of the vehicle.

The Navy has a continuing requirement to develop and test new weapon system concepts that could benefit from VR systems. This is a natural extension of eliminating the need for physical simulators and mockups. New weapons, and new concepts for deploying those weapons in the battlefield, can be simulated in the virtual world. New weapon system concepts can be explored without the expense of developing prototypes. Onlookers can invisibly take a point of view from anywhere within the battlefield to evaluate tactics and strategies. Information that is invisible to human senses can be examined visually or audibly in the virtual world.

Reducing information overload in time-critical decision making is another key area

VR concepts as SuperCockpit can be extended to other military domains requiring analysis of vast amounts of information in a very limited amount of time. This is especially true of applications in command, control, communications, and intelligence.

In each of the above applications, a 3D display is integrated with sensors, positioning data, mission profile data, and video equipment to record the user's efforts. However, a field survivable 3D display is anticipated for "live-fire" data collection during missions to enhance the situation awareness and fast-breaking action for the user.

BRAIN WAVE MEASUREMENT

The Artisan Group is working with the Westinghouse Science and Technology Center in Pittsburgh, Pa. in the adaptation of a proprietary brain wave measurement technology for use in VR systems. This system will provide an objective method for analyzing memory, thinking, and attention to virtual environments. The system is composed of the modern principles of the polygraph examination with event related potentials generated by the subject's brain during VR immersion.

The brain wave technology consists of two subsystems: real-time and off-line. The primary function of the real-time subsystem is to digitize electroencephalographic (EEG) data, time and control the presentation of stimuli to the subject, record reaction time, perform on-line analysis, detect artifacts, average event related potential (ERP) responses, and display ERP and EEG data. The off-line subsystem performs media management, data archival and retrieval, construction of the test stimuli, data analysis, and data display.

To date, the basic system has been used for training tape evaluations for a RADAR system, cognitive evaluation for the diagnosis of organic syndromes, visual and hearing testing, and focus group testing and product evaluation. Soon, cue combination studies of virtual environments will be underway that will yield critical data on stereopsis, motion, occlusion, texture gradient, long-term experience, and highlighting. These results could yield revolutionary concepts on VR design and application.

The Navy has a requirement to develop and test new weapon systems that could benefit from VR systems

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FIGURE 1. Sonobuoy field coverage. (Photo courtesy of the U.S. Navy, NCCOSC RDTE)

TACTICAL 3D DISPLAY

3D and other display technologies are being studied for their application to tactical Naval operations at the new Naval Command, Control and Ocean Surveillance Center (NCCOSC) as the Research, Development, Test and Evaluation Division. Among the potential beneficiaries of this technology are airborne early warning and forward air control, platform and force level battle management, air traffic control, compact flight trainers and mission planners, and many aspects of antisubmarine warfare (ASW). This mission area is being investigated for the improvement of shipboard ASW sensor information displays.

Performance with displays improves when operator workload is reduced, and this effect is amplified by prolonged operations. Therefore, displays that minimize this workload should result in improved operator performance and improved decision making. The need, therefore, is for displays that present information in ways that take advantage of natural human perceptual and cognitive skills. Few display systems in use today are more abstract than those used to support the ASW mission area.

Existing ASW displays present information that is frequently truncated, filtered, or otherwise simplified because of limitations in data processing or the physical limitations of the display devices themselves. Currently, the sonar operator must create a mental model of the multidimensional ASW environment based on multidimensional acoustic, physical, and temporal information that has been presented in a very abstract visual 2D format from several sources. The application of new 3D visual and audio display technologies to this problem could yield significant improvements in operator performance and operational effectiveness. These 3D systems could present the critical tactical information in a far more intuitive and integrated way, thereby reducing the cognitive interpretation burden and learning time while improving the tactical success rate over current systems.

An advanced technology ASW display system could consist of:

- The application of 3D, stereoscopic, high-resolution, full color, helmet-mounted or boom-mounted displays
- A 3D position tracker (for the helmet-mounted display) and 3D manipulators for computer function control
- The incorporation of 3D audio for presentation of multiple beams from the sonar for intuitive cuing and correlation of acoustic information to the ocean environment
- Automated speech recognition
- The intuitive depiction of high-resolution computer-generated imagery of the ASW environment based on integrated display of active, passive, and environmental sensor information.

The exact nature of the displays that may prove most effective are yet to be determined, but speculation unfettered by display constraints leads to some intriguing possibilities.

For example, in the active sonar mode the 3D ASW display could provide the operator with a 360° field-of-regard image of the ocean bottom topography and water properties integrated with wave fronts representing the propagation of the sonar pulses. The operator would see these wave fronts reflected off the local topography and all known obstacles in that database and refracted by the model of the local water properties. The operator would therefore be able to see which returns are from known obstructions and compare that with the actual returns received by the sonar. Integrating this 3D visual representation with acoustic analysis and cuing from the 3D audio system would give the operator an intuitive picture of the ASW situation.

Similar display approaches could be used for fixed site ASW facilities. Application of

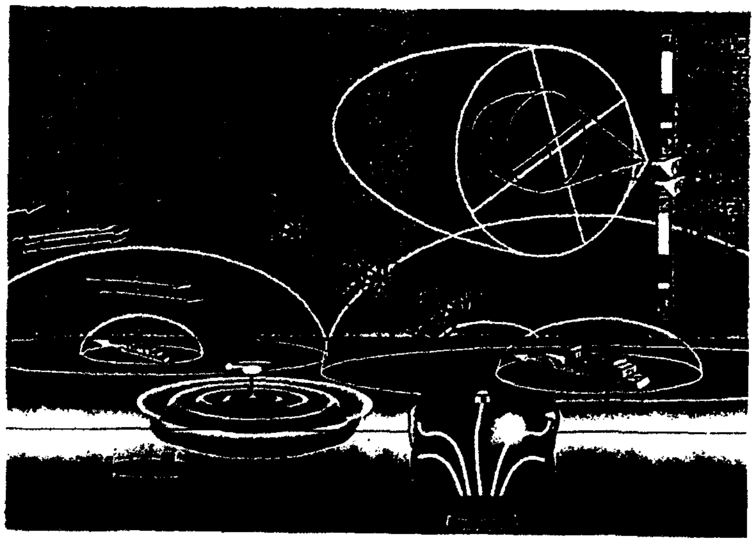


FIGURE 2. Command level imagery. (Photo courtesy of the U.S. Navy, NCCOSC RDTE)

such a display system to airborne ASW is more challenging due to the strict size and weight limits of ASW aircraft but computer size and weight are constantly decreasing. Many of the displays developed for surface ASW would be directly applicable to both airborne and ashore ASW. A few specialized displays may be added for such things as sonobuoy coverage, however (Figure 1).

This technology could also be applied to ASW tactical support by providing the shipboard ASW officer or submarine approach officer with a 3D image of the ocean environment, the weapons engagement envelops, sensor coverage volumes, and the hostile submarines that have been identified. In a similar way, it could be applied to the display of battle management information (Figure 2) where the location and status of assets determines the weapons and sensor coverage.

3D display technology could also provide E-2C controllers with 3D aircraft engagement information including launch envelopes, detection system coverage, and so on. A simpler application would be for air traffic control afloat or ashore where only limited organic sensor information must be presented. Such a system might also benefit from the incorporation of real-time voice control of the communications system.

THE TECHNOLOGIES

Four technologies are maturing sufficiently to permit a serious investigation of their operational use in an integrated information display system. They are high speed graphics computers, miniature high resolution displays, 3D position sensors, and digital 3D audio.

High speed graphics computers can generate acceptably realistic imagery that is updated fast enough to present an operator with useful information in real time. These machines are using multiple processors to achieve dramatic speed and cost improvements with large supercomputers now operating with thousands of processors. Today's high-speed graphics computers will seem slow by the time a 3D display system is ready to enter the Fleet.

Miniature high-resolution displays evolved from weapons control and sensor display requirements for military aircraft. Although the Navy fielded the first operational helmet-mounted display (HMD), the most widely used of these systems can be found aboard Marine Corps and Army combat helicopters. These systems now use cathode ray tubes (CRTs) as small as 0.5 inches in diameter with 1,000 line resolution. Approximately 1,000 line resolution is required for "seamless" imagery in an HMD with an aver-

age field [illegible]. By way of comparison TVs generally range from 350 to 550 lines high. All of these small CRTs are either monochrome or black and white. Small, high resolution full-color CRTs will be commercially available this year.

Color active-matrix liquid crystal displays (LCDs) for the miniature TV market are being used for displays in most commercial stereoscopic systems. These displays have doubled in linear resolution to the point of being comparable with standard television resolution (LCD image height of 480 pixels vs. 500 lines of raster-scan video for conventional TV). Although this is a great improvement over the previous generation of 240 pixel-high LCDs, this resolution is still low enough that the image appears very grainy when magnified as part of a stereoscopic display system. Fortunately, higher resolution color LCDs are likely to emerge on the commercial market within five years because of a Defense Advanced Research Projects Agency (DARPA) funded research effort at the David Sarnoff Research Center.

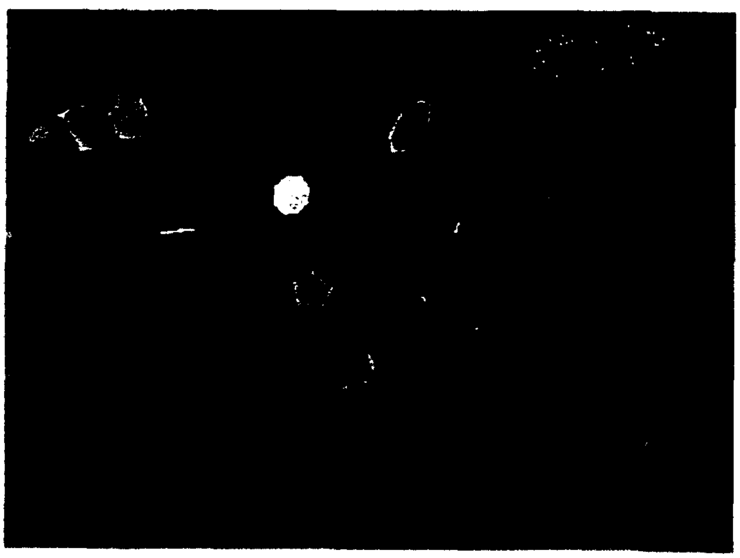
The most prevalent 3D position sensor system today uses a magnetic field generator affixed to the local environment and a field sensor attached to the device to be monitored. A computer system monitors the field sensor and calculates the position and attitude of the sensor based on the nature of the portion of the magnetic field in which it is immersed. These units are small and rugged, but they are sensitive to the presence of ferrous metals that can distort the magnetic field geometry. Work is being done to reduce this problem and to speed up the operation of the system. Other position trackers are now reaching the commercial market, however. One unit uses multiple ultrasonic sensors and sources to monitor position and attitude. An analogous multi-element infrared system is also available. These systems are not sensitive to electromagnetic interference [illegible] have their own limitations.

3D audio is perhaps the [illegible] technologies that support the [illegible] display information effectively. [illegible] growth of research into human auditory perception. Initial research demonstrated the importance of the shape of the outer ear to the localization of sounds. Subsequently, the ability to modify sounds using experimentally derived transform functions was achieved. The transform functions were derived by measuring the distortion of known broad-band sounds due to outer ear shape. An undistorted sound, after processing by a transform function incorporated into circuitry, would seem to have emanated from any desired location. This made it possible to alter a sound so that it would seem to have come from any chosen location in space external to the listener. Recent work at National Aeronautics and Space Administration (NASA) Ames Research Center resulted in these transforms being incorporated into digital circuitry and married to computers that could simultaneously monitor the orientation of the operator's head (using a 3D position tracker) and transform a sound so that it would seem to be stationary while the operator moved.

THE FUTURE

These technologies are already being applied to numerous civilian tasks including architecture; mechanical design in the automotive and aerospace industries; pharmaceutical research; medical imagery for 3D display of CAT scan, NMR, and ultrasonic medical data; education; entertainment; and functional aids for the handicapped. If these new technologies are properly applied to the tactical Naval environment, their impact on operational effectiveness and training methods and systems could be dramatic.

History has taught us that the requirement to operate a global Navy will not diminish at a rate commensurate with the decrease in our assets. Budgets and staff levels will probably continue to decrease over the next decade or two. Therefore the workload for each person will increase, and the tactical cost of losing one platform out of a reduced inventory will be magnified. Systems that can improve operational performance while requiring lower staffing will be critical, and those systems that can achieve the greatest performance improvements at the lowest cost will be essential. ☆



TOPES, designed by Rudy Rucker, demonstrates the physical properties of objects pictured. Built with the Autodesk Cyberspace Developers Kit. (Photo courtesy of Autodesk)

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